Detection of Imported Fire Ant (Hymenoptera: Formicidae) Mounds with Satellite Imagery

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ABSTRACT Satellite imagery (0.65-m resolution, panchromatic) was tested as a detection tool for imported fire ant mounds in northeast Mississippi pasture. Photointerpretation of satellite imagery resulted in an average detection rate of 46.9 ± 1.2% of mounds. Mound size and mound height had a significant effect on mound visibility. Predicted detection rates, based on mound height and mound area, ranged from 24% for small mounds (15 cm high, 0.05 m^2) to 66% for large mounds (30 cm high, 0.30 m^2). Limitations and possible uses for satellite imagery in fire ant mound detection are discussed.

KEY WORDS remote sensing, photointerpretation, imported fire ants

RED IMPORTED FIRE ANTS (*Solenopsis invicta* Buren) and black imported fire ants (*S. richteri* Forel) were accidentally introduced into the United States (1918–1940). Imported fire ants and their hybrid currently infest nearly 130 million ha in the southern United States, California, and Puerto Rico. The black and hybrid forms occur in northern Mississippi and Alabama and southern Tennessee. For a review of the establishment and spread of these ants, see Callcott (2002).

Imported fire ants construct large, conspicuous earthen mounds. Green et al. (1977) successfully detected ≈80% of fire ant mounds in airborne photographs of infested Texas coastal plain areas. Seasonal mound building activity and changes in vegetation covering mounds were important factors influencing mound visibility in their images. Fresh soil excavated by the ants during periods of mound-building activity (primarily winter and early spring) exhibited low reflectance of near-infrared light, causing mounds to appear as dark spots on images. Lush vegetation immediately surrounding mounds appeared as a bright red halo in near infrared images, resulting in a dark spot—red halo signature.

Efforts to track the status of fire ant infestations over large areas after recent introductions of self-sustaining biological control agents (*Pseudacteon* spp. decapitating flies [Diptera: Phoridae]) (Graham et al. 2002, Porter et al. 2004, Vogt and Streett 2004) may benefit from development of remote sensing techniques for mound detection. Additionally, as imported fire ant populations expand into previously uninfested areas, remote sensing could play a valuable role in surveying for mounds, particularly in difficult to reach areas. The objective of this project was to assess the feasibility of using commercial satellite data to detect black and hybrid fire ant mounds in northern Mississippi pasture. Using panchromatic satellite imagery (450–900 nm black and white) the dark spot—halo signature described by Green et al. (1977) might not be discernible, but decreased overall reflectance of the mound surface relative to surrounding vegetation would result in a dark spot signature for photointerpretation. Because of the size of mounds and the current limits for resolution of commercial satellite data (≈0.6 m), I hypothesized that data would be useful for detection of large mounds (>0.36 m^2).

Materials and Methods

The study site was a floodplain/prairie bottom pasture (263 ha) in Clay County, MS. The site contained a mixture of clay prairie bottom soils (Catalpa-Griffith) and mixed prairie bottom soil (Leeper). Vegetation was primarily Bermuda grass (*Cynodon* sp.) and fescue (*Festuca* sp.), with patches of small trees and shrubs. Sampling was conducted on either side of a riparian buffer that extended from the north end of the area to the southeast corner.

Satellite imagery (panchromatic, 0.65-m resolution) of the study site was obtained from DigitalGlobe Geographic Information Products (Longmont, CO) in late December 2002. All GPS data were obtained with a Starlink Invicta 210 DGPS/Beacon Receiver (Starlink, Austin, TX) and recorded in SoloField CE (Tripod Data Systems, Corvallis, OR). Plots (≈0.4 ha each; $N = 9$) were established and georeferenced within the study site. A team of four workers on the ground searched each plot thoroughly for imported fire ant

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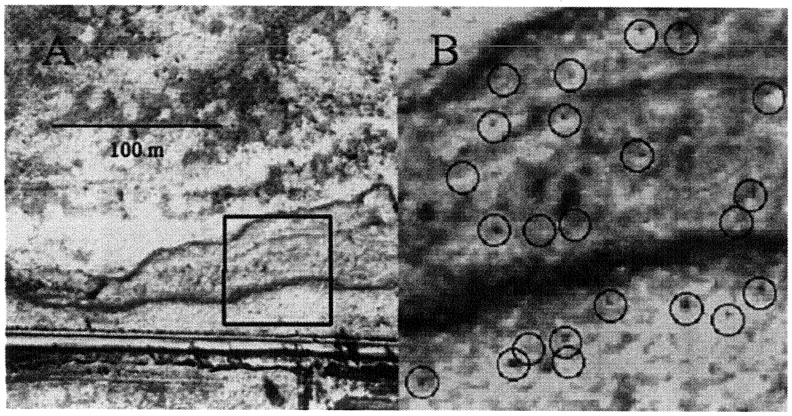

Fig. 1. Panchromatic, 0.65-m resolution satellite imagery of north Mississippi pasture. Image is from west side of study area. Boxed area in A is magnified in B; imported fire ant locations (determined using GPS on the ground) are circled. Contains material copyrighted from DigitalGlobe, 2002.

mounds. Each mound was measured and georeferenced. Fire ant mounds tend to be elliptical (Hubbard and Cunningham 1977); therefore, mound area was determined using the equation

$$\text{Area} = \pi \times a \times b$$

where a is the semimajor axis, and b is the semiminor axis. Mound activity was determined by creating a small (≈1 cm wide by 5 cm long) opening in the mound surface to see if worker ants rushed out to defend the colony. Vegetation cover was determined for each mound by visually estimating the percentage of the raised mound surface obscured by emerging vegetation. Ground truth data were obtained within 2 wk of data capture to minimize error caused by colony movement.

Mounds were classified using photointerpretation. In a blind test, plot outlines were overlaid onto image data in ArcGIS (ESRI, Redlands, CA) and visually examined for details that resembled fire ant mounds. Each suspected mound was marked, and mound location data were overlaid onto the image to check accuracy of detection. Commission errors (points representing suspected mounds, where no actual mound was present) and omission errors were tallied for each plot. A model to predict probability of observing a mound was developed using Proc Mixed (Littell et al. 1996), with plot as a random block effect, mound activity (one for active, two for inactive) as a fixed classification effect, and vegetation cover, mound area, and height as covariates.

Data were also examined using ENVI software (Environment for Visualizing Images; Research Systems, Boulder, CO) to get an estimate of differences in reflectivity between mounds and the surrounding ground surface and/or vegetation. Histogram equalization was applied to the image to increase contrast, and screen values (brightness values; 0–255) were obtained for 20 individual pixels contained within visible mounds (one per mound). Twenty additional pixels were chosen at random, one from the area immediately surrounding each mound. Brightness of pixels within and outside of mounds was compared using a *t*-test.

Data are presented as means ± SE. Means were considered different at the $\alpha = 0.05$ level.

Results

Imported fire ant mounds showed evidence of recent building activity during the time of data acquisition and were easily located on the ground. Mounds appeared on the satellite imagery as dark spots against a light background (west side of study area) or light spots against a dark background (east side of study area). Images were analyzed at a scale of ≈1:780; at this scale, individual pixels were clearly evident, but several mounds were also visible (Figs. 1 and 2). Imagery was acquired at an off-nadir angle of 14°, resulting in a ground sample distance of ≈65 cm.

An average of 46.9 ± 1.2% of mounds were detected in the satellite image (range, 33–70%/plot). Photointerpretation resulted in an average of 7.4 ± 0.7 commission errors per plot (range, 2–16). There was an average of 28 ± 1.2 mounds per plot (range, 9–48). Potential overestimation caused by commission errors ranged from 9.5 to 55%.

Photointerpretation resulted in a score of "visible" (1) or "not visible" (0) for each mound present; thus, this experiment was a Bernoulli trial resulting in a binomial random variable. Sufficient *N* (251) allowed assumption of normality for the mean predicted response within the range of interest; thus, data were analyzed using Proc Mixed to model probability of observing a mound. After considering models that included area, height, vegetation cover, and all possible interactions, the simplified model that was selected was

$$P = -0.029(\pm 0.079) + 0.015(\pm 0.004) \times \mathrm{H} + 0.808 \quad (\pm 0.352) \times \mathrm{A}$$

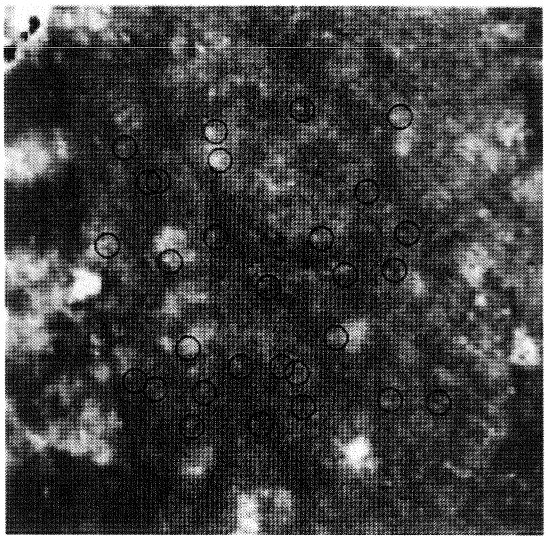

Fig. 2. Panchromatic, 0.65-m resolution satellite imagery of north Mississippi pasture. Image is from east side of study area; note light appearance of fire ant mounds (circled, determined using GPS on the ground) against dark background. Contains material copyrighted from DigitalGlobe, 2002.

where P is the predicted probability of detecting a mound of height H (cm) and area A (m^2) ($F = 13.5$, df = 1,242, $P = 0.0003$ and $F = 5.4$, df = 1,246, $P = 0.0211$ for height and area, respectively). Some predicted values are given in Table 1.

Screen values (brightness values) for pixels within mounds were lower than the surrounding area west of the riparian zone ($t = -6.6$, df = 9, $P < 0.0001$), and higher than the surrounding area east of the riparian zone ($t = 5.5$, df = 9, $P = 0.0004$; Table 2).

Discussion

Satellite imagery seems to have some limited use as a detection tool for locating imported fire ant mounds. As hypothesized, larger mounds were more likely to be visible than smaller mounds, with predicted detection reaching ≈66% (Table 1).

Several factors may affect mound visibility. Soil type can influence mound characteristics of fire ant colonies (e.g., in loose, sandy soil mounds tend to be flatter). Soil moisture and/or soil type could influence

Table 1. Predicted probability of imported fire ant mound detection using 0.65-m resolution, panchromatic satellite imagery, based on mound height and area

Mound ht (cm)	Probability of mound detection[a]		
	Mound area = 0.05 m^2	Mound area = 0.15 m^2	Mound area = 0.30 m^2
15	0.24	0.32	0.44
30	0.46	0.54	0.66

[a] Predicted using the equation $P = -0.029 + 0.015 \times H + 0.808 \times A$, where P is probability of detection.

Table 2. Mean screen values (brightness) of pixels within and outside of fire ant mounds in 0.65-m resolution, panchromatic satellite imagery

Pixel source	Mean screen value ± SE[a]	
	West side of site	East side of site
Within mound	105.3 ± 10.6a	83.0 ± 10.7b
Outside mound	183.8 ± 14.4b	40.4 ± 7.0a

[a] Means within the same column followed by the same letter are not significantly different (t-test, $P > 0.05$).

mound reflectivity. In general, mounds in the western half of the study area appeared as dark spots against a light background (Fig. 1), and mounds located within the eastern half of the study area appeared as light spots against a dark background (Fig. 2). The eastern half of the study area is ≈2 m higher in elevation than the west side, with a gentle slope toward the riparian buffer; mounds on the eastern side tend to dry more quickly after rain. Four to 7 d before data acquisition, the area received ≈6 cm of rainfall; there was no rain for 3 d before sampling, but conditions remained wet on the west side of the area, with scattered pools of standing water. Additionally, vegetation was sparse on the east side of the area relative to the west side. On the east side, exposed, moist soil provided a dark background for the drier, more reflective mounds, and on the west side, relatively moist mounds contrasted with thick vegetation. The time of day for data acquisition influenced shadow effects, which may have a positive influence on mound visibility because of mound height. Data were acquired at ≈1030–1040 hours, and some shadow was evident in the image. Finally, season is likely to have an effect, because of seasonal changes in the vegetation surrounding mounds and variation in mound building activity (e.g., Green et al. 1977).

While photointerpretation is inherently subjective as an analytical tool, it is the technique that is most readily available to researchers and regulatory personnel who may not have access to powerful image processing software. Familiarity with the general appearance of fire ant mounds and an understanding of how changes in environmental conditions can alter mound building activity are required of anyone using this technique for detection of imported fire ant mounds. This study was designed primarily to test photointerpretation of raw data (GeoTIFF format). Additional techniques (image classification, image transformations) may prove useful and are the subject of ongoing experiments. Variation in the reflectance of mounds in this study (Table 2), in areas <200 m apart, suggests that any image processing designed to enhance the appearance of mounds or automate their detection will be useful over limited areas that share certain characteristics (soil moisture, vegetation). Preliminary work suggests that usefulness of classification techniques and/or image transformations will be limited at this relatively low resolution.

Sources of error (lack of detection of smaller mounds, commission errors) may make currently available satellite imagery unsuitable for applications

where a high level of precision in sampling is required. Commission errors are problematic; however, experience in photointerpretation would likely reduce error, and knowledge of typical fire ant mound densities could be used as a guide for determining whether an area is truly infested. For detection, satellite imagery may prove useful for guiding personnel to suspected infestations on the ground. As spaceborne sensor technology improves and higher resolution data become available to the public, satellite imagery may play an important role in large scale imported fire ant monitoring and suppression programs.

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